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Climate change and associated spatial heterogeneity of Pakistan: Empirical evidence using multidisciplinary approach

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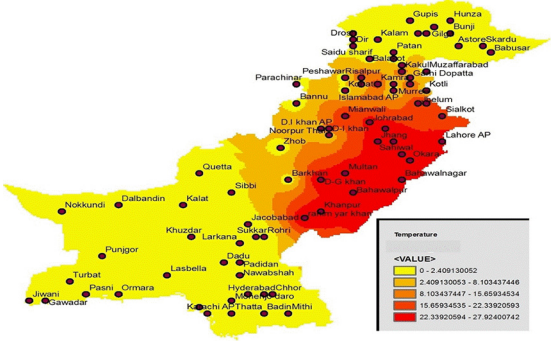
HIGHLIGHTS

- Real time-based quantification of climate change and heterogeneity are explored for Pakistan.
- Empirical changes in climate are analyzed and mapped provincially from 1960 to 2014.
- Econometric assessment of the domestic drivers of climate change
- Mean annual temperature has been increased by 0.57 °C from 1960 to 2000.
- The warmest year—in Pakistan—on record was 2004 followed by 1988.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change is a multidimensional phenomenon, which has various implications for the environment and socio-economic conditions of the people. Its effects are deeper in an agrarian economy which is susceptible to the vagaries of nature. Therefore, climate change directly impacts the society in different ways, and society must pay the cost. Focusing on this truth, the main objective of this research was to investigate the empirical changes and spatial heterogeneity in the climate of Pakistan in real terms using time series data. Climate change and variability in Pakistan, over time, were estimated from 1961 to 2014 using all the climate variables for the very first time. Several studies were available on climate change impacts, mitigation, and adaptation; however, it was difficult to observe exactly how much change occurred in which province and when. A multidisciplinary approach was utilized to estimate the absolute change through a combination of environmental, econometric, and remote sensing methods. Moreover, the Autoregressive Distributed Lag (ARDL) model was used to ascertain the extent of variability in climate change and information was digitalized through ground truthing. Results showed that the average temperature of Pakistan increased by 2 °C between 1960 and 1987 and 4 °C between 1988 and 2014, and R^2 was 0.978. The rate of temperature increased 0.09 °C between 1960 and 2014. The mean annual precipitation of Pakistan increased by 478 mm, and its R^2 were 0.34–0.64. The mean annual humidity of Pakistan increased by 2.94%, and the rate of humidity has been increased by 0.97% from 1988 to 2014. Notably, Sindh and Balochistan provinces have shown a significant spatial heterogeneity regarding the increase in precipitation. Statistically all variables are significant. This would serve as a baseline information for climate change-related studies in Pakistan and its application in different sectors. This would also serve the plant breeders and policymakers of the country.

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Table 1
Results of bounds F-test.

Critical values at 95% level of significance		F – calculated
Lower bound I(0)	Upper bound I(1)	
4.0461	5.1315	6.0760

1. Introduction

Climate change—the mother of major externalities—has caused extreme weather events like temperature fluctuations, humidity changes, and heavy precipitation, leading to great economic losses (Changnon et al., 2000; Prudhomme et al., 2003; Xia et al., 2012). A recent report from the Intergovernmental Panel on Climate Change (IPCC) revealed that global average temperatures increased by 0.3–1.7 °C (IPCC, 2015). Short-run and long-run extreme events caused changes in climate (Larsen et al., 2011; Mitsch and Hernandez, 2013). Changes in environmental conditions, such as durability and service life of temperature and humidity, affect the structure. Temperature is one of the most typical climatic factors (Liu et al., 2012; Zhulidov et al., 2011). Climate change effects vary in different geographical areas; extreme events show great regional differences in both ways (i.e., positive and negative). There have been significant positive trends observed in Europe (Rajczak and Preethi, 2012), in the UK (Chan et al., 2014; Dos et al., 2011), and in Japan (Kamiguchi and Tamai, 2011); transversely significant trends in the United States (Kunkel et al., 2013) and in Australia (Fiddes et al., 2015); and extreme precipitation and different parameters, including positive and negative amplitude trends, observed in

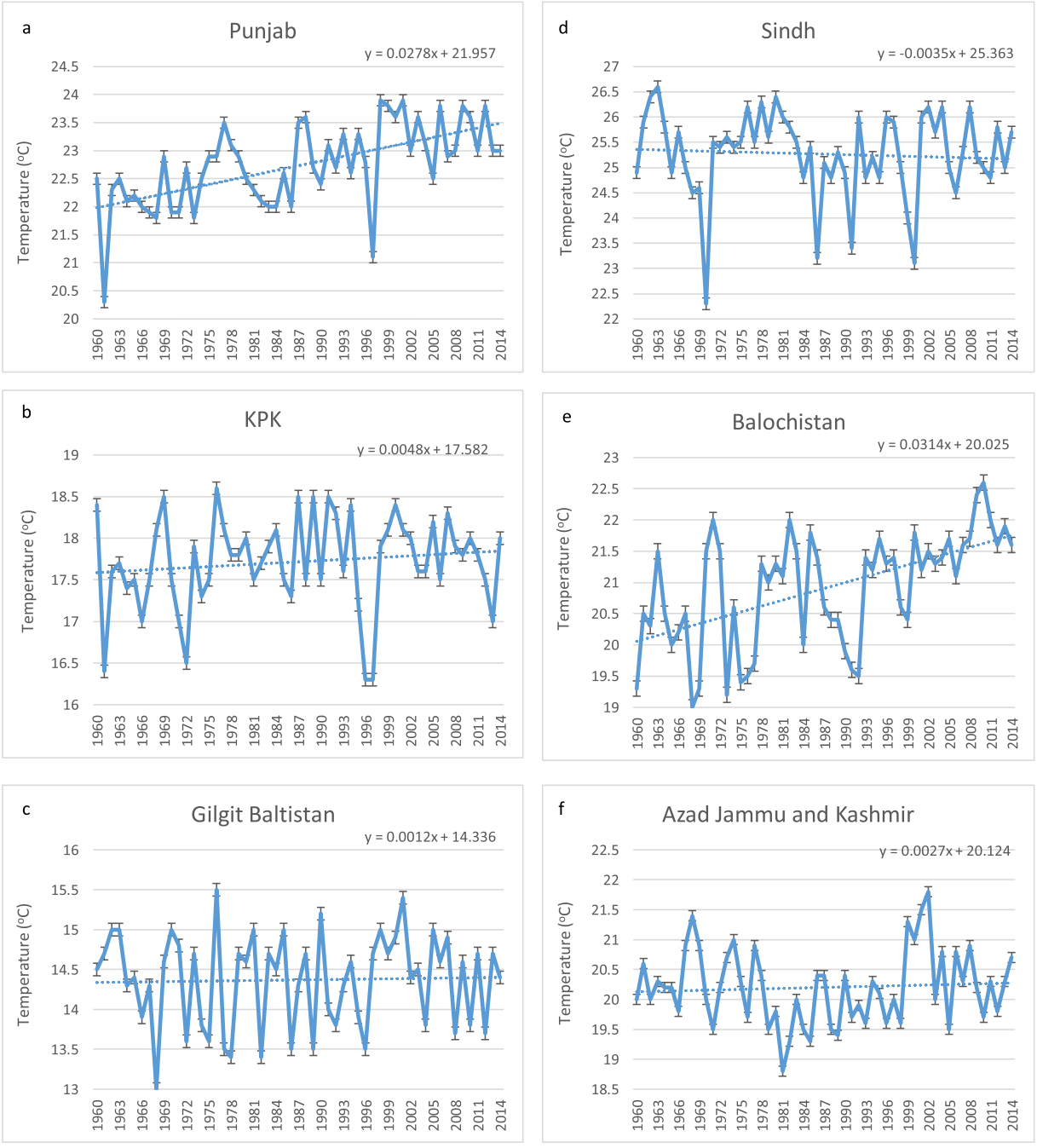


Fig. 1. Temperature trend lines from 1960 to 2014 (a) Punjab province (b) Khyber Pakhtunkhwa province (c) Gilgit Baltistan (d) Sindh province (e) Baluchistan province (f) Azad Jammu & Kashmir.

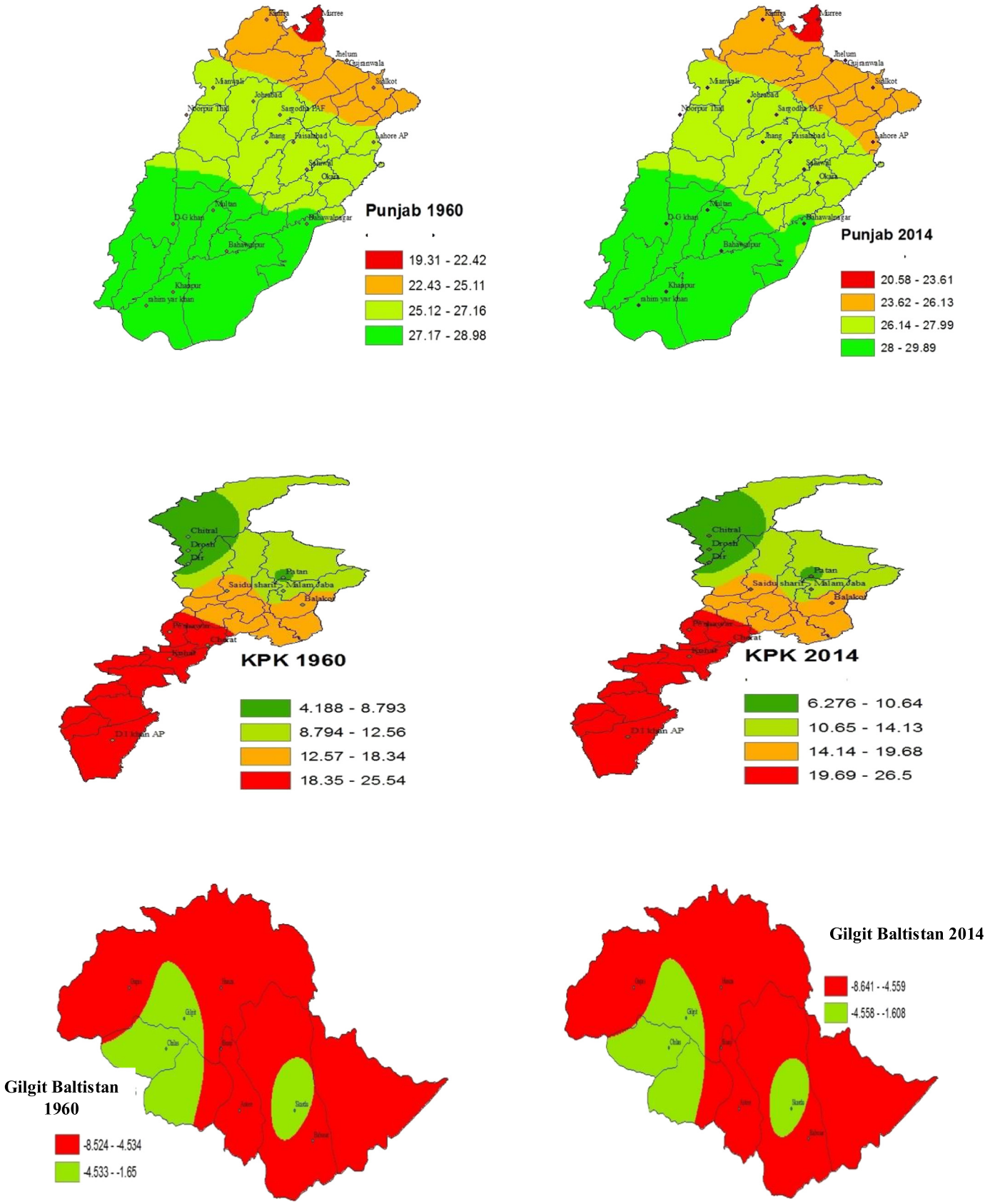


Fig. 2. Variations in temperature of provinces of Pakistan on comparative basis (1960 & 2014).

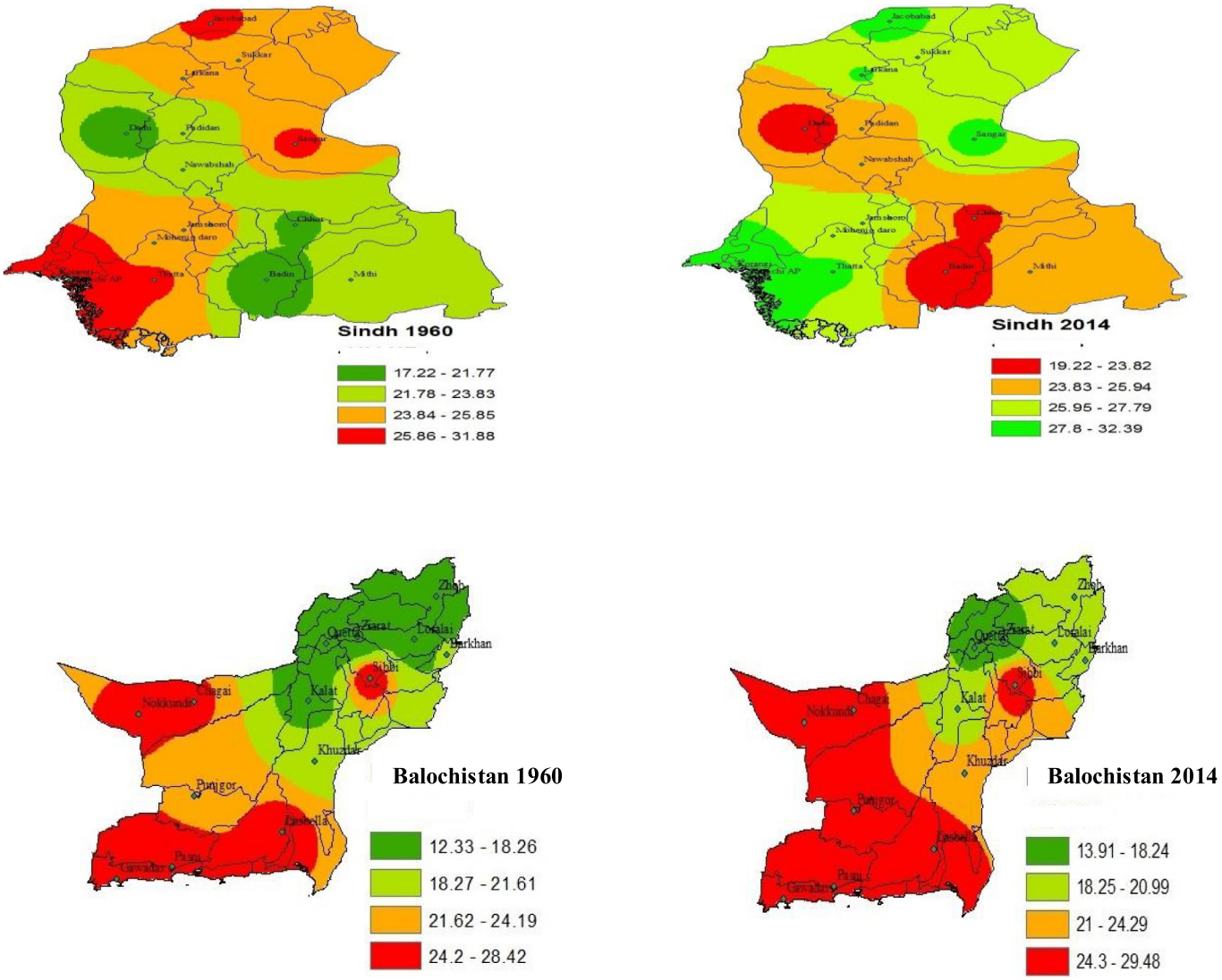


Fig. 2 (*continued*).

India (Preethi et al., 2011; Revadekar and Preethi, 2012) and in China (Bernstein and Cashore, 2012; You et al., 2011).

Existing research reveals that climate change has been influenced by a combination of global factors such as environmental problems (Ali et al., 2017; Fredriksson and Gaston, 2000; Neumayer, 2002; Stein, 2008). However, to our knowledge, there is as yet no global econometric assessment of the domestic drivers of climate change. Some researchers have conceptualized the impact of climate change on crops (Ghazala and Arif, 2009; Haider et al., 2008), climate change mitigation (Afzaal et al., 2009; Chaudhary and Rasul 2004; Haroon and Afzal, 2012; IPCC, 2007a, 2007b), and adaptation of climate change (Mahmood and Rasul, 2012; Maida and Rasul, 2011; Rasul et al., 2008), but no one has quantified the actual climatic changes systematically and statistically and mapped them for the climate of Pakistan.

In the recent past, some authors (e.g., Sheikh et al., 2015) considered extreme temperature indexes over South Asia. Choi et al. (2009a, 2009b) also examined changes in temperature extremes in some countries of Asia, and other authors (Revadekar et al., 2012; Milly et al., 2002; Min et al., 2011; Mladjic et al., 2011; You et al., 2011; Zhang et al., 2011; Wang et al., 2013) testified to the impact of altitude and latitude changes in temperature extremes over South Asia.

The comprehensive nature of the data allowed one to study variation dynamics econometrically and draw statistically rigorous conclusions. We have used the data to test some hypotheses, which are derived directly from the climate change debate, or explore findings from other areas that apply to climate change (e.g., on the importance of a strong executive). Over the past few decades, some studies on maximum and minimum temperature trend lines have been documented in Pakistan (Afzaal et al., 2009; Chaudhary and Rasul 2004; Ghazala and Arif, 2009; Haider et al., 2008; Haroon and Afzal, 2012; Mahmood and Rasul, 2012). At the local level, a few studies have primarily focused on the major cities of the country; for instance, Sadiq and Qureshi (2010) investigated maximum and minimum temperatures from 1961 to 2007 for five major cities of Pakistan. Likewise, Sajjad et al. (2009) discussed trends for Karachi city; Cheema et al. (2006) discussed trends for Faisalabad city; and Sadiq and Ahmed (2010) observed variations in minimum and maximum temperatures for Chaklala, Pakistan.

The study in hand is a novel one, in the context of Pakistan, in that complete climatic variables are included, such as temperature, precipitation, and humidity, which were missing in previous studies. Likewise, several studies have been available on climate change impacts, mitigation, and adaptation; however, it has rarely been observed how much change occurred and in which areas. Furthermore, empirical time series evidence was not available previously. This study has tried to spotlight empirical evidence countrywide using 54 years of time series data. For the very first time, the trends of climate change in Pakistan have been mapped based on empirical information and discussed in detail. Data keeping/collection is a challenge in Pakistan because most districts

lack meteorological departments and have a weak data inventory system. Another new aspect of this research study is that it utilizes an econometric model (ARDL) and remote sensing techniques to map historical variability and changes. The purpose behind using ARDL is its ability not only to arrange and describe the complicated interactions among various elements at different levels but also to deal with dynamic processes and feedback in a system. Additionally, it can predict complex system changes under different "what-if" scenarios and is good at implementing scenario analysis and providing decision support. Since the development of the ARDL model, the method has been applied to various fields, including ecological modeling, transportation planning, and regional environmental management. This paper tries to fill such knowledge gaps to provide better resources for policy makers. It could be useful for increasing awareness among all concerned stakeholders, especially the policy makers, for helping in decision making. Therefore, the main aim of this research was to investigate the empirical changes and spatial heterogeneity in the climate of Pakistan and to map them historically from 1960 to 2014. Moreover, through this study, a hypothesis was tested narrated as H_0 (there is no absolute change in climate) and H_1 (there are absolute changes in the climate).

2. Materials and methods

2.1. Study area

Pakistan is an autonomous country in South Asia, located between the latitudes 24°N–37°N and longitudes 60°E–75°E. It borders the Arabian Sea, between India in the east, Iran, and Afghanistan in the west,

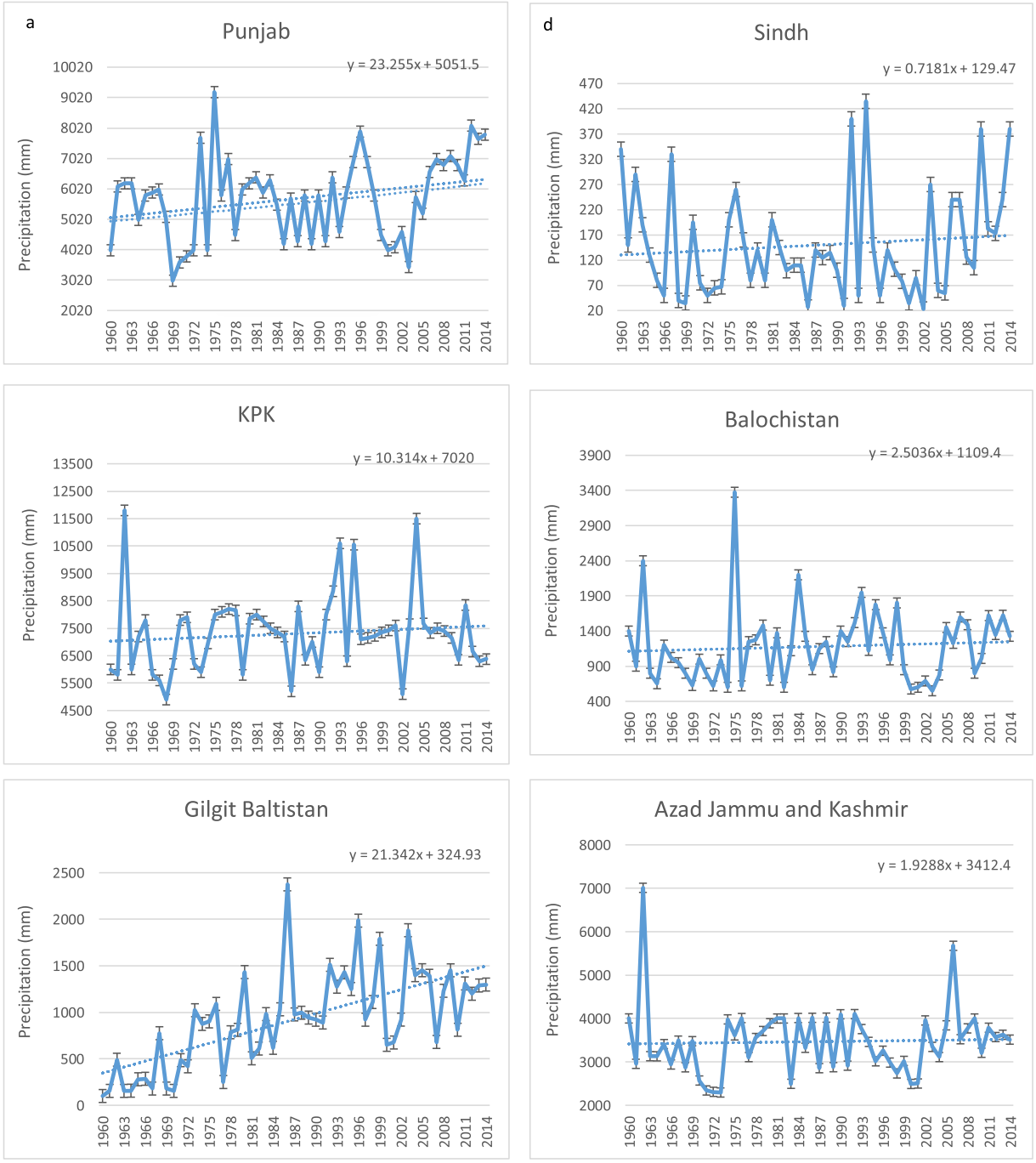


Fig. 3. Perception trend lines from 1960 to 2014 (a) Punjab province (b) Khyber Pakhtunkhwa province (c) Northern areas (d) Sindh province (e) Balochistan province (f) Azad Kashmir.

and China in the north. The climate of Pakistan shows an extensive continuum from region to region, ranging from arid to humid. It is blessed with the monsoon rainfall in summer and rainfall from western systems in winter. The climate is generally arid to semiarid, characterized by hot summers and cold winters, with significant variations between extremes of temperature at given locations (Ali and Nitivattananon, 2012), except on the southern slopes of the Himalayas and in the submountain region, where the annual rainfall ranges from 760 mm to 2000 mm (Chaudhary and Bawa, 2011).

2.2. Data collection

Historical data on climate variables (temperature, precipitation, and humidity) for the last 54 years (1960–2014) were obtained from the Pakistan Meteorological Department (PMD) for different districts. The data were arranged according to province and were analyzed in order to compute historical changes in the climate of Pakistan on an empirical basis. Maps and graphs were drawn for mean annual and seasonal rainfall, maximum, minimum and mean temperatures. The main sources of data were taken from the PMD, the Hydrocarbon Development Institute of Pakistan (HDIP), the Environmental Protection Agency of Pakistan, and the Ministry of Climate Change, Pakistan.

2.3. Methodology

Six provinces were part of the climate change analysis, i.e., Punjab, Khyber Pakhtunkhwa, Sindh, Balochistan, Azad Jammu and Kashmir, and Gilgit-Baltistan (also called as Northern Areas). Data were available from Punjab (24 districts), Khyber Pakhtunkhwa (17 districts), Sindh (14 districts), Balochistan (13 districts), Gilgit-Baltistan (10 districts), and Azad Jammu and Kashmir (5 districts) only. A multidisciplinary approach was utilized to measure the exact value of the change in the climatic variables. This approach was used for measuring the complexity which usually was not possible for the estimation of such values through stimulation of a single model. Different models were stimulated for estimation of the variation in the climate of Pakistan. ARDL model was simulated to determine the overall change in temperature, precipitation, and humidity in different provinces of Pakistan. The

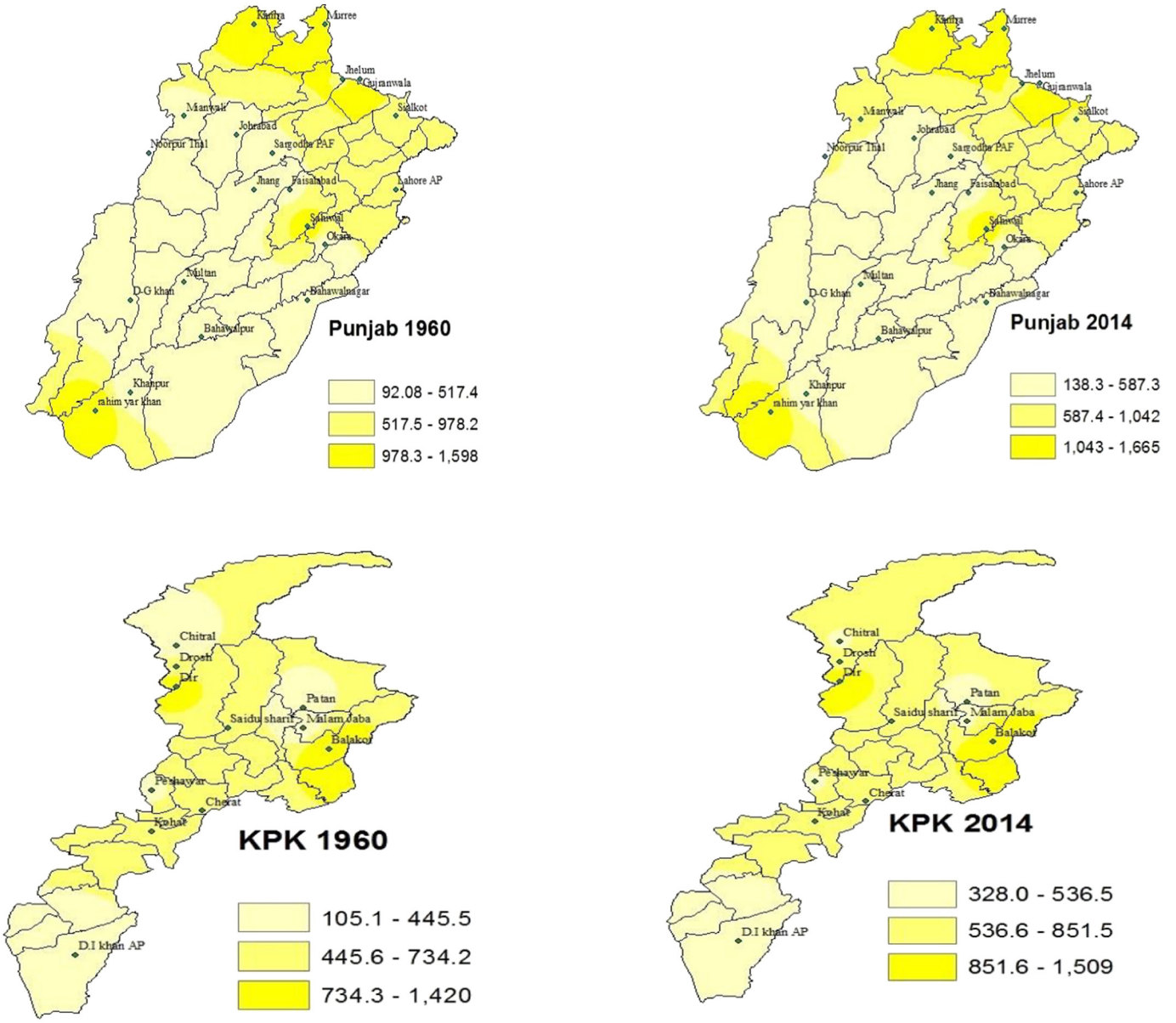
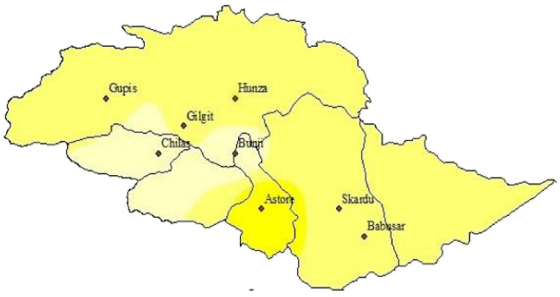


Fig. 4. Variations in precipitation of provinces of Pakistan on comparative basis (1960 & 2014)

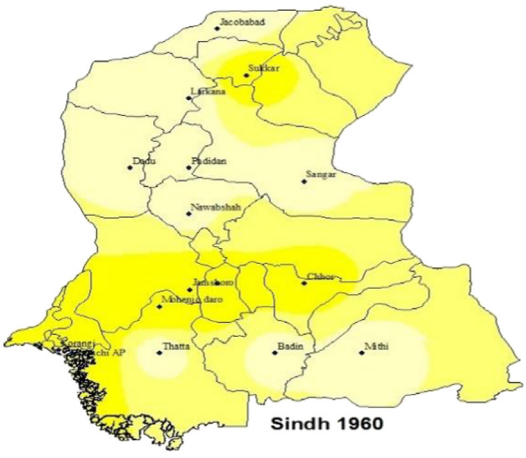


Gilgit and baltistan 1960

59.54 - 136.2
136.3 - 181.9
182 - 238.9

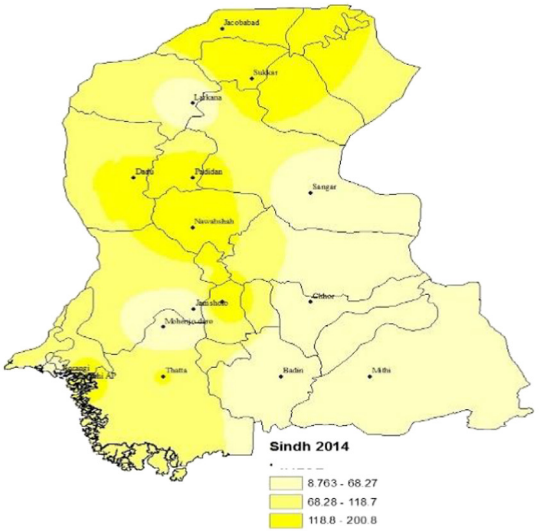
Gilgit and Baltistan 2014

84.6 - 205.5
205.6 - 312.5
312.6 - 479.9



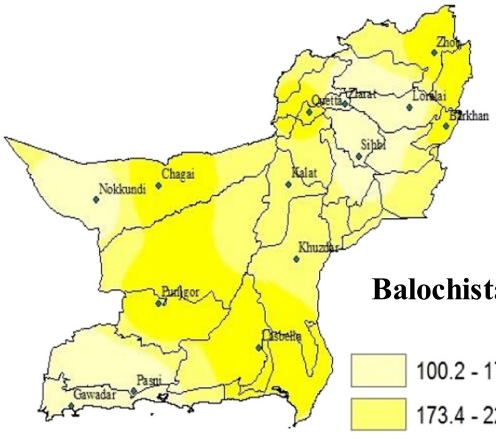
Sindh 1960

81.82 - 141.9
142 - 168.8
168.9 - 216.2



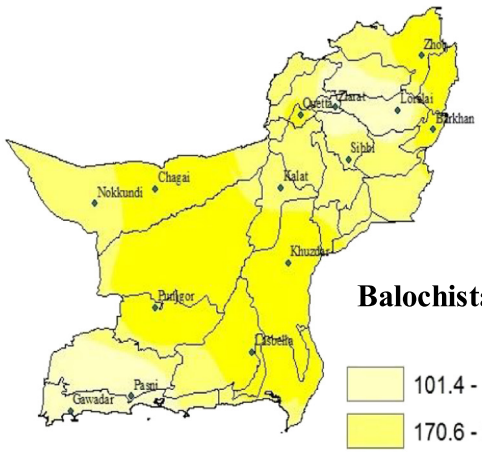
Sindh 2014

8.763 - 68.27
68.28 - 118.7
118.8 - 200.8



Balochistan 1960

100.2 - 173.3
173.4 - 224.9
225 - 283



Balochistan 2014

101.4 - 170.5
170.6 - 223.9
224 - 283

purpose behind to use ARDL was its ability not only to arrange and describe the complicated interactions among various elements at different levels but also to deal with dynamic processes and their feedback in a system. Additionally, it can predict complex system changes under different 'what-if' scenarios and is good at implementing scenario analysis and providing decision support.

2.3.1. Tests for the long-run relationship

To evaluate long-run coefficients, the autoregressive distributed lag approach model was used. When selecting this model, numerous simulations were run. Variables used in this study I (0) or I (1) or co-integrated models have consistent results. It is unnecessary to add those variables which explain stationarity at similar levels. If endogenous variables were involved in the model the consequences would be unbiased. When using ARDL, the t-statistics attained would be valid. If dynamics are included, even in the existence of endogeneity bias, then consistent results can be attained. The results can be improved upon if a small sample size is taken to convent co-integration methods. When simply transformed an ARDL model, an error correction model (ECM) can also be derived. This ECM can be used as an auxiliary model to create a short-run relationship between variables. Having said that, in light of the benefits mentioned above, a subsequent ARDL equation was created for the variables in order to execute the model.

$$\mathrm{Temp}_t = \alpha_0 + \sum_{i=1}^{n}\alpha_0\Delta(\mathrm{precipt})_{t-1} + \sum_{i=1}^{n}\beta_i\Delta\,(\mathrm{humdt})_{t-i} + \eta_1(\mathrm{precipitation})_{t-1} + \eta_2(\mathrm{humidity})_{t-1} + \varepsilon_t \quad (1)$$

where, the coefficients α_o,β_i display short-run impacts whereas the coefficients since η_1 and η_2 point towards the long-run relationship, which are the coefficients of the lagged variables display. ε_t illustrates the zero-mean besides constant variance, white noise error term, and α_0 is the float module.

The first step to evaluating the presence of a long-run relationship between the variables is by measuring the long-run coefficients. For this purpose, the Bounds F-test was used. For the F-test, OLS was applied and the lagged coefficient was restricted for the null hypothesis.

H_0: $\eta_1 = \eta_2 = 0$.

H_1: $\eta_1 \neq \eta_2 \neq 0$.

The critical bounds values were compared with the F value. Critical bounds values have two asymptotic independent variables I (d) with $0 \leq (d) \leq 1$. The lower bound would assume all of them to be I (0), while the upper bound would assume all regressive to be I (1). The null hypothesis would be rejected if the F-statistic lies above the upper bound while the null hypothesis would be accepted if F-statistics lies below the lower bound. However, if it lies within the range of the bounds, the result will be inconclusive.

2.3.2. Test for the short-run relationship

The error correction model was derived from ARDL model, for estimation of the short-run model. ECM shows the speed of adjustment of the model that whether equilibrium or disequilibrium exist. If the coefficient of ECM is significant then long-run relationship exists, in case of non-significant then short-run relationship exists. With the change in coefficient of ECM dependent variable changes the level of disequilibrium in the co-integration relationship and changes in the other explanatory variables befell. Any deviation in the coefficient of ECM will change the dependent variables in the long run relationship:

$$\Delta\mathrm{Temp}_t = \alpha_0 + \sum_{i=1}^{n}\alpha_i\Delta(\mathrm{precpt})_{t-1} + \sum_{i=1}^{n}\beta_i\Delta\,(\mathrm{humidt})_{t-i} + \Phi_t\mathrm{ECM}_{t-1} + \varepsilon_t \quad (2)$$

where explanation of other factors is same as for Eq. (1); ECM_{t-1} error correction term, ϕ_t shows the speed of adjustment to the long run equilibrium.

2.3.3. Mapping of climate change data

ArcGIS is a geographic information system (GIS) tool used for creating maps and geographic information. Moreover, compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications and managing geographic information in a database are also salient functions of this tool. The system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the web. ArcGIS 10.2 was used in order to create maps for this study.

3. Results and discussion

Climate indicators and the variability of climate change in Pakistan have been analyzed through this research study analysis. For the first time, we analyzed temperature, precipitation, and humidity, and subsequently found them to be the key parameters for climate analysis. Of long-term data collected, which ranges from 1960 to 2014, climate variables are the major data required to calculate the change and variability in the climate of Pakistan. It was interesting to find that the signals of climate change in the country are consistent with the change of opinion regarding the phenomena of global warming. Table 1 explained the values of the lower bound and upper bound, 4.0461 and 5.1315, respectively, at a level of significance of 95%. If compared to the value of F, when calculated with the lower bound and upper bound, this value is smaller yet. Therefore, the null hypothesis can be rejected in favor of an alternative hypothesis. From such results, it can be determined that there is a significant long-term relationship between temperature and explanatory variables. The following sections give a detailed explanation of historical changes, as well as long-term and short-term relationships in Pakistan's climate.

3.1. Spatial heterogeneity in the temperature of Pakistan

From 1960 to 2014, the data were available and collected from 24 meteorological stations of the districts of Punjab province. The mean monthly temperature has been shown in Fig. 1(a) for the Punjab province. Between 1960 and 1987, the mean maximum temperature increased by 0.96 °C (Celsius), while between 1988 and 2014, the mean maximum temperature increased by 1.21 °C. There was also a significant increase in the maximum temperatures in the Sialkot, Murree, and Faisalabad districts (i.e., 3.09 °C, 2.38 °C, and 2.23 °C, respectively). The mean minimum temperatures increased by 0.93 °C between 1960 and 1987, while there was an increase of 1.03 °C between 1988 and 2014. Likewise, data were obtained from 17 districts of KPK province. The mean monthly temperature of KPK has been shown in Fig. 1(b). The mean maximum temperature increased by 0.97 °C between 1960 and 1987; while between 1988 and 2014, the temperature increased by 0.71 °C. A substantial increase in the maximum temperature was also found in the districts of Cherat, Kakul, and Parachinar, (i.e., 1.81 °C, 1.21 °C, and 1.11 °C, respectively). The mean minimum temperature decreased by −0.24 °C between 1988 and 2014. Another data set was acquired from PMD for Gilgit-Baltistan—for the period of the selected years—showed interesting results. The data were collected from 10 districts of the Gilgit-Baltistan of Pakistan. The mean monthly temperature can be observed in Fig. 1(c). Between 1960 and 1987, the mean maximum temperature increased by 0.95 °C, while between 1988 and 2014, the mean maximum temperature increased by 0.98 °C. A change in the maximum temperature in the Hunza, Gilgit, and Astore districts (i.e., 1.7 °C, 1.5 °C, 1.3 °C, respectively), was clearly demonstrated in the analysis. The mean minimum temperature decreased by −0.29 °C between 1988 and 2014.

For the Sindh province, the data of 14 districts were available. From the available data, it is clear that the mean monthly maximum temperature increased by 0.97 °C between 1960 and 1987, whereas between 1988 and 2014, the mean maximum temperature increased by 0.70

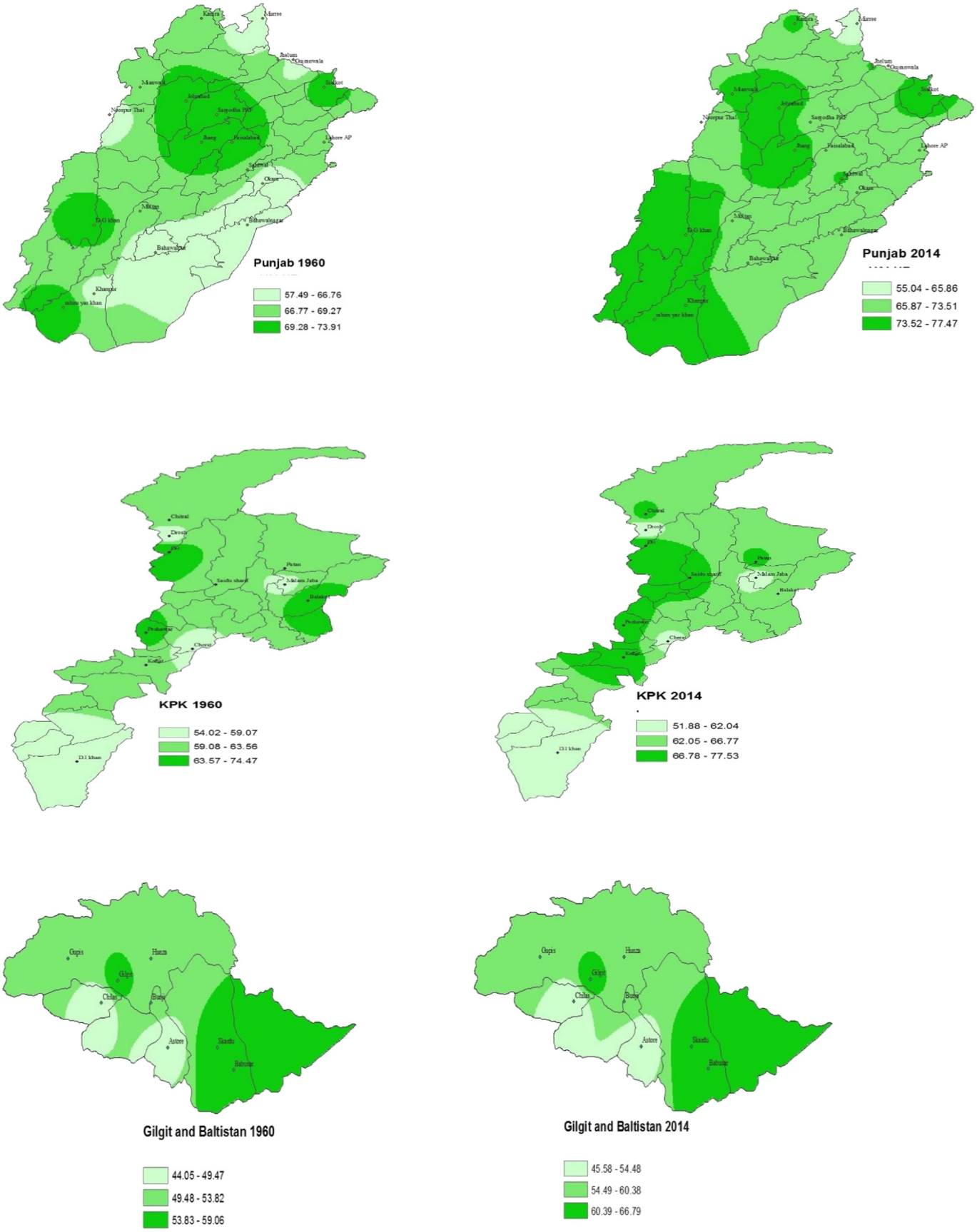


Fig. 5. Variations in humidity of provinces of Pakistan on comparative basis (1960 & 2014).

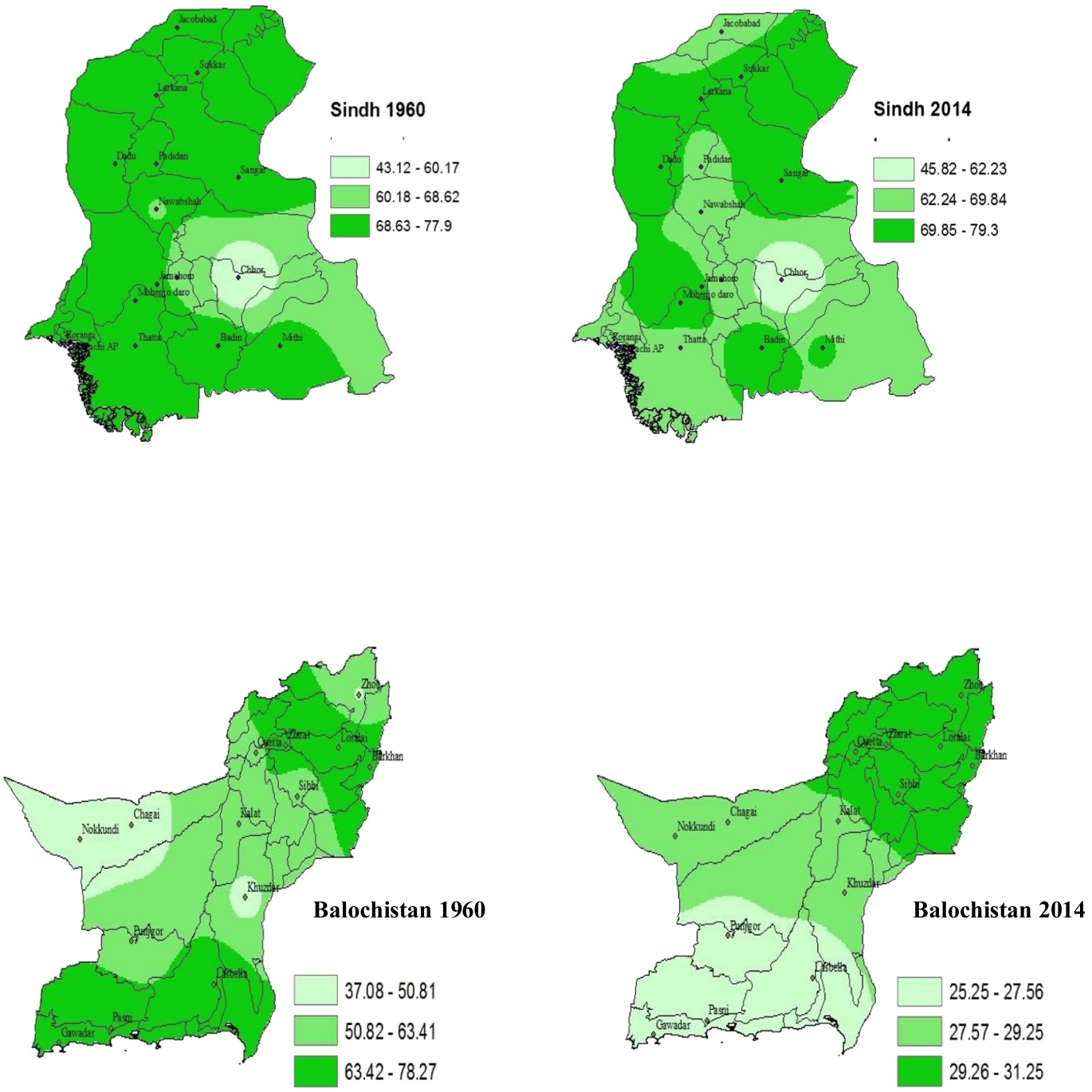


Fig. 5 (*continued*).

°C. An increase in maximum temperature in the districts of Chhor, Karachi, and Nawabshah (i.e., 3.2 °C, 1.7 °C, 1.4 °C, respectively), was also observed (see Fig. 1(d)). Hence, the mean minimum temperature decreased by −0.003 °C between 1988 and 2014, thus representing a very minute change. A total of 13 districts of Balochistan province are equipped with meteorological stations, and the data were collected from all of the stations in operation. Fig. 1(e) shows the mean monthly maximum temperature between 1960 and 1987 spiked by 0.95 °C, while between 1988 and 2014, the mean maximum temperature amplified by 1.30 °C. An increase in maximum temperature in the districts of Kalat, Pasni, and Sibbi (i.e., 2.6 °C, 2.5 °C, 2.4 °C, respectively), was also noticed, with the mean minimum temperature increasing by 0.81 °C between 1988 and 2014. Five districts in the Azad Kashmir province of Pakistan were available for data and are currently in operation. The mean monthly temperature is shown in Fig. 1(f). Between 1960 and 1987, the mean maximum temperature increased by 0.97 °C, while between 1988 and 2014, the mean maximum temperature increased by 0.72 °C. There was a significant increase in maximum temperature in the districts of Ghari Dupatta and Muzaffarabad (i.e., 1.4 °C and 0.68 °C, respectively), were existent. The mean minimum temperature increased by 0.005 °C between 1988 and 2014. Fig. 2 explained the mean temperature of the provinces of Pakistan for two comparative years (1960 and 2014). Interestingly, increasing trends have been found in all provinces for temperature. The highlighted areas of the map showed that the highest temperature had been observed, while others showed the lowest temperature observed in each province.

Table 2
Estimated long run coefficients by using ARDL.

Variable	Coefficient	Standard error	T-ratio [prob]
HUM	0.23091	0.054933	4.2034 [0.000]
PRECIP	−0.0021004	0.0017752	−1.1832 [0.242]
C	8.0618	3.6533	2.2067 [0.002]

Table 3
Error correction representation for the selected ARDL model.

Variable	Coefficient	Standard error	T-ratio [prob]
dHUM	0.16283	0.047877	3.4010 [0.001]
dPRECIP	−0.0014811	0.0011895	−1.2452 [0.219]
ecm(−1)	−0.70516	0.13669	−5.1589 [0.000]

3.2. Variations and spatial heterogeneity in precipitation

Data sources and collection methods, which were followed for all analyses, are explained in Section 2 of this paper. A province-wide analysis was performed to investigate the variability in precipitation between 1960 and 2014 and the consequent spatial heterogeneity of the provinces of Pakistan. Hence, precipitation data were obtained from 12 districts of the Punjab province. The mean annual precipitation is shown in Fig. 3(a). Between 1961 and 1987, the mean annual precipitation was 512 mm (mm), whereas between 1988 and 2014, the yearly average precipitation increased to 591 mm. A significant increase in annual precipitation in Sialkot, Mianwali, and Bahawalnagar districts (i.e., 209 mm, 180 mm, 148 mm, respectively) was observed. The mean annual precipitation increased by 78 mm between 1988 and 2014. Ten districts in KPK province were in operation, and data were collected from all of them. The mean annual precipitation is in Fig. 3 (b). Between 1961 and 1987, the mean annual precipitation was 707 mm, while between 1988 and 2014, the mean annual precipitation was 833 mm. A substantial increase in annual precipitation in the districts of Chitral, Dir, and Parachinar (i.e., 377 mm, 366 mm, 228 mm, respectively) was found from the results. The mean annual precipitation increased by 125 mm between 1988 and 2014. Similarly, the data were acquired from seven districts in the Gilgit-Baltistan. The mean annual precipitation is shown in Fig. 3(c). Between 1961 and 1987, the mean annual precipitation was 141 mm, while between 1988 and 2014, the mean annual precipitation was 266 mm. A change in the form of increased annual precipitation was witnessed in the districts of Astore, Chilas, and Gupi (i.e., 241 mm, 123 mm, 103 mm, respectively). The mean annual precipitation increased by 125 mm between 1988 and 2014.

For the Sindh province, data were gathered from nine districts for the years between 1961 and 2014. The mean annual precipitation is shown in Fig. 3(d). Between 1961 and 1987, the mean annual precipitation was 152 mm, while between 1988 and 2014, the mean annual precipitation was 186 mm. The increased annual precipitation in the districts of Jacobabad, Chhor, and Nawabshah (81 mm, 81 mm, 55 mm, respectively) showed a substantial change. The mean annual precipitation increased by 34 mm between 1988 and 2014 for the Sindh province of Pakistan.

Similar data and information were gathered for the Balochistan province between 1961 and 2014. The data were obtained from 10 districts of Balochistan. The mean annual precipitation is shown in Fig. 3 (e). Between 1961 and 1987, the mean annual precipitation was 201 mm, while between 1988 and 2014, the mean annual precipitation was 218 mm. A significant increase in annual precipitation in the districts of Sibbi, Khuzdar, and Kalat (66 mm, 62 mm, 14 mm, respectively) was analyzed and presented. The mean annual precipitation increased by 16 mm between 1988 and 2014.

Last but not least, for the Azad Kashmir province, data were obtained from five districts of Azad Kashmir province. The mean annual precipitation is shown in Fig. 3(f). Between 1961 and 1987, the mean annual precipitation was 1246 mm, whereas between 1988 and 2014, the mean annual precipitation was 1291 mm. A comprehensive increase in the annual precipitation (234 mm) in Muzaffarabad district was observed. The mean annual precipitation increased by 44 mm between 1988 and 2014. Fig. 4 maps the mean precipitation of Pakistan (province-wise) for the two selected years—the 1960 base year and the 2014 final year of observation. The highlighted areas of the map showed that the highest precipitation had been observed, and that the other sides showed the lowest precipitating changes in those areas. It is interesting to note that there were changes in every province regarding precipitation, however, variation and heterogeneity certainly exist among the provinces. Most notably, the Sindh and Balochistan provinces have shown a significant spatial heterogeneity regarding the increase in precipitation. Gilgit Baltistan province has also shown a considerable variation in the precipitation over the determined period. Comparatively, rest of the regions did not show a significant change and contributed less in the spatial heterogeneity analysis of this study. Such changes in precipitation are also consistent with the changes found in the previous section.

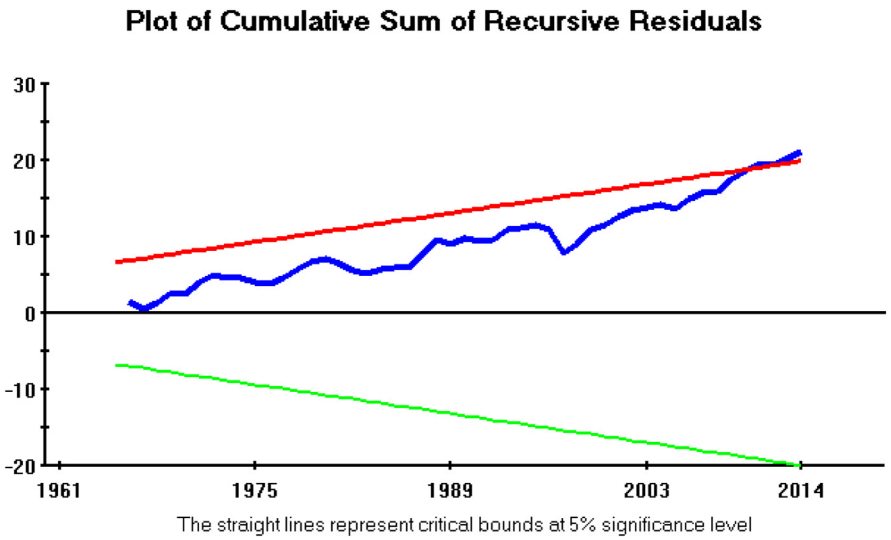


Fig. 6. Cumulative sum of recursive residuals.

Table 4
Test results for the reliability of the model.

Item	Test applicable	CHSQ	Probabilities
Serial correlation	Lagrange multiplier	0.11963	0.729
Functional form	Ramsey's reset test	0.0010617	0.974
Normality	Test of skewness and kurtosis	15.2289	0.000
Heteroscedasticity	Regression on square residuals (white)	0.31087	0.577

3.3. Humidity and spatial heterogeneity

Concerning temperature and precipitation, the same pattern of analysis and explanation of results are presented to maintain the flow of the study and to understand the changes. Data were obtained from 12 districts of Punjab Province from 1960 to 2014. The mean annual humidity has been analyzed and presented in this section. From 1961 to 1987, the yearly average humidity was 67% while between 1988 and 2014 the mean annual humidity was 71%. An increase in annual humidity in the districts of Khanpur, Bahawalnagar, and Sialkot of 8%, 7%, and 6% respectively was observed. The mean annual humidity increased by 3% from 1988 to 2014. For KPK Province, data were gathered from 10 districts. From 1961 to 1987, the mean annual humidity was 62% whereas between 1988 and 2014 the yearly mean humidity was 64%. A substantial increase in annual humidity in the districts of Chitral, Chirat, and Peshawar of 8%, 5% and 3%, respectively, was observed. The mean yearly humidity increased by 2% from 1988 to 2014. Likewise, data were collected from 7 districts of Gilgit-Baltistan. From 1961 to 1987, the mean annual humidity was 56% while between 1988 and 2014 the mean annual humidity was 51%. A significant increase in annual moisture in the districts of Gilgit, Bunji, and Chilas of 7%, 6%, and 1%, respectively, was observed. The mean annual humidity increased by 5% from 1988 to 2014. In Sindh Province, meteorological stations of 9 districts were in operation and data were collected from all of them. From 1961 to 1987, the mean annual humidity was 67% whereas between 1988 and 2014, the mean annual humidity was 69%. An increase in annual humidity in the districts of Jacobabad, Rohri, and Padidan of 5%, 4%, and 4%, respectively, was observed. The mean annual humidity increased by 1% from 1988 to 2014.

Data were collected from 10 districts of Balochistan province. From 1961 to 1987, the mean annual humidity was 55% while between 1988 and 2014, the mean annual humidity was 54%. A significant increase/decrease in annual humidity in Sibbi, Quetta, and Pasni districts of 4%, −3%, and −3%, respectively, was observed. The mean annual humidity decreased by −1% from 1988 to 2014. This depicts a real change and heterogeneity in the climate of Pakistan from the perspective of Balochistan Province. Azad Kashmir Province of Pakistan was also analyzed in the same manner from 1961 to 2014. The data were obtained from 5 districts of Azad Kashmir. From 1961 to 1987, the mean annual humidity was 68% whereas between 1988 and 2014, the mean annual humidity was 73%. A significant increase in annual humidity of 5% was observed in each of Gari Dupatta, Kotli, and Muzaffarabad districts. The mean annual humidity increased by 6% from 1988 to 2014. Overtime change in humidity has been mapped and showed in Fig. 5. Such detailed empirical analyses of climate indicators of Pakistan showed huge variation and spatial heterogeneity. Despite some increasing trends in humidity in different provinces of Pakistan, there is some decrement as well. Balochistan province showed a different heterogeneity regarding humidity decrement from 1988 to 2014. This is a fascinating finding. Such findings overall combined and presented a holistic climate change picture of Pakistan which have never been reported in such a way earlier. Therefore, it is valid to ascertain that climate has been changed in Pakistan over the last 50 years and a spatial heterogeneity exists there.

3.4. Long run and short run results from modeling

The long-run results for ARDL model are presented in Table 2. Here, temperature denotes a dependent variable and humidity or precipitation are independent variables. The elasticity of humidity, in the long-run, is 0.23091, standard error of the humidity is 0.054933, and t-calculated of the humidity is 4.2034, and it is statistically significant, which means that by 1% increase in humidity, temperature increases by 0.23091%. The elasticity of precipitation, in the long run, is −0.0021004, standard error of the precipitation is 0.0017752, and t-calculated of the precipitation is −1.1832, and it is statistically non-significant, which means that by 1% increase in precipitation, temperature decreases by 0.0021004%. The statistical analysis results further showed that the constant has a positive sign with statistically significant value. The elasticity of the constant in the long run is 8.0618, standard error of the constant is 3.6533, and t-calculated of the constant is 2.2067, and it is statistically significant, which means that even when all variables show no or zero change in the model then in the long-run, still the temperature of Pakistan will change by 8.0618% (Fig. 6).

The short-run results by using Error Correction Representation for the selected ARDL model are explained in Table 3. Here, the elasticity of humidity in the short run is 0.16283, standard error of the humidity is 0.047877, and t-calculated of the humidity is 3.4010, and it is

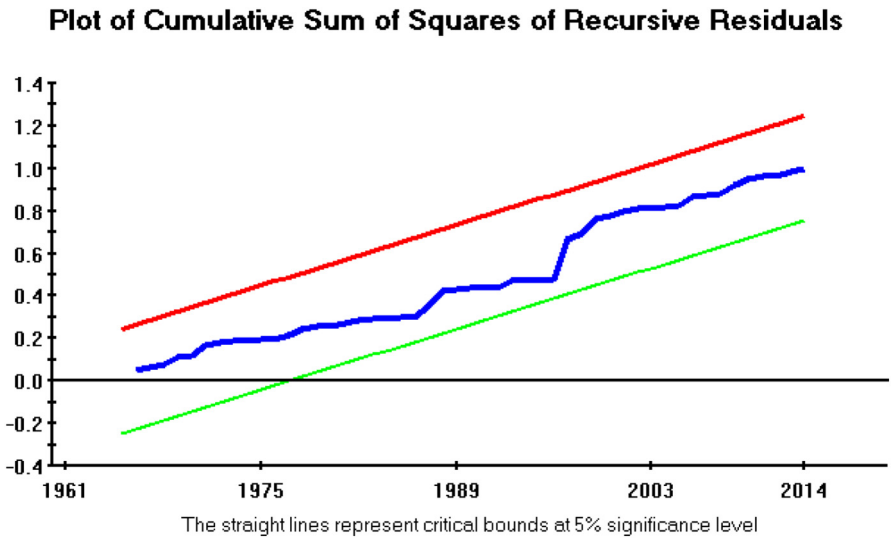


Fig. 7. Cumulative sum of square of recursive residuals.

statistically significant, which means that with 1% increase in humidity, temperature increases by 0.16283% and demonstrates an immediate effect. The elasticity of precipitation in the short run is −0.0014811, standard error of the precipitation is 0.0011895, and t-calculated of the precipitation is −1.2452, and it is statistically non-significant, which means that when precipitation increases by 1%, temperature decreases by −0.0014811% due to its non-significance. The elasticity of error correction term in the long run is −0.70516, standard error of the error correction term is 0.13669, and t-calculated of the error correction term is −5.1589, and it is statistically non-significant, which means that by 1% increase in error correction term, temperature decreases by −0.0014811% due to its non-significance. In short run, 70% of disequilibrium was revealed in the study. In the first year, disequilibrium will adjust 54%. In the third year, disequilibrium will adjust 30%. From Table 4, it apparent that from the econometric point of view that the problems of autocorrelation have not been observed due to the divergence of the normal distribution. Technically, no heteroscedasticity, no specification error and no functional form exist in this model. Conclusively, this model presented satisfied and justifiable results showing long run and short run results of variability and change (Fig. 7).

3.5. Stability of the model

Two tests were applied to check the stability of the model: Cumulative Sum of Recursive Residuals (CUSUM) and Cumulative Sum of Square of Recursive Residuals (CUSUM Q) test. It is imperative to check the stability of the model, for the study objectives. For this purpose, hypothesis tests, which were set included:

H_0: All coefficients in the model are stable.

H_1: All coefficients in the model are unstable.

If we plot CUSUM and CUSUM Q; which results in their limitation to inside the boundary, the model is considered stable and correspondingly, the null hypothesis is accepted at 5% level of significance. Conversely, if CUSUM and CUSUM Q, fall outside the boundary, the model is considered unstable and the null hypothesis is correspondingly rejected, at 5% level of significance.

4. Conclusions

The main aim of this research was to investigate the empirical changes and spatial heterogeneity in the climate of Pakistan and to map them historically. Several studies on climate change impacts, mitigation, adaptation, and related modeling have been conducted by numerous researchers; however, studies investigating real climate change in Pakistan in quantitative terms are rare to find. Furthermore, all information on climate change is digitally mapped to establish a baseline inventory and closely analyze spatial heterogeneity for all provinces. The overall mean annual temperature in Pakistan increased by 0.57 °C from 1960 to 2000, and it also rose by 0.47 °C from 2000 to 2014, indicating a change of −0.10 °C in the last decade. The total temperature increase from 1960 to 2014 was 0.09 °C. The warmest year on record in Pakistan was 2004, followed by 1988. Summer means a temperature increase of 0.89 °C, 0.22 °C, and 0.02 °C in Balochistan, Punjab, and Sindh, respectively. The temperature in the KPK and AJK provinces decreased by 1 °C, 0.26 °C, and 0.04 °C, respectively. A significant increase in mean winter temperatures from 1.12 °C to 0.52 °C in all regions in the country was observed. Likewise, means of precipitation and humidity showed increasing and decreasing trends in different provinces. This helped confirm the existence of spatial heterogeneity in Pakistan with respect to climate change. The rate of climate change is different for different provinces. Although obvious increasing trends in temperature, precipitation, and humidity have been noted, a few declining trends have also been observed.

Hence, all ground reality-based data and resultant analyses indicated significant changes in climate variables in Pakistan. Statistical modeling results revealed that the independent variable (precipitation) was statistically nonsignificant as a temperature-dependent variable. This means that when precipitation held constant, the temperature in Pakistan remained at an average of 8 °C. The results showed that humidity was statistically significant as a temperature-dependent variable. Empirical evidence has been provided through this study in the case of Pakistan. Therefore, climate changes may affect any economic sector, especially the agriculture sector (which is the largest economic sector in Pakistan). Production of major crops is affected as temperature increases: for example, the water use efficiency of C3 plants increases when temperatures rise. This is helpful information to provide to breeders as well as to policymakers. As food for thought, our results tend to indicate that not all changes in climate are necessarily negative; such changes can have a positive impact. Therefore, before diving too deep into the analysis of the impact of climate change or mitigation/adaptation models and solutions, policymakers would be smart to clarify assumptions regarding whether such change is positive or negative, and then craft applicable policies. This kind of analysis and baseline assessment would significantly help future studies in this regard.

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